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Kellie Ann Beall, Editor

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OPTICAL PROPERTIES OF SOOT IN THE OVERFIRE REGION OF LARGE BUOYANT TURBULENT DIFFUSION FLAMES

by

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Introduction. Information about the optical properties of soot is needed in order to develop optical measurements of soot properties and to compute soot radiation in flame environments. Unfortunately, current estimates of soot optical properties involve excessive uncertainties due to uncertainties about soot refractive indices [1]. Wu et al. [2] sought to correct this deficiency by measuring the refractive index properties of soot in the overfire region of large gaseous hydrocarbon fueled buoyant turbulent diffusion flames burning in still air where soot properties depend on the fuel but are independent of position and flame residence time [3,4] by exploiting the properties of Rayleigh-Debye-Gans scattering theory for polydisperse fractal aggregates (denoted RDG-PFA theory) which has been recently shown to be effective for soot optical properties [5,6]. Unfortunately, measurements of soot dimensionless extinction coefficients due to Wu et al. [2] were not in good agreement with contemporary measurements of Dobbins et al. [7] and Choi et al. [8] which raises questions about the corresponding accuracy of their refractive index measurements. Thus, the present study sought to resolve this issue by completing similar measurements of soot optical properties, again considering soot in the overfire region of large buoyant turbulent flames but for a broader range of both gas and liquid hydrocarbon fuels burning in still air.

Experimental Methods. The soot was produced by round burners exhausting into a large collection hood followed by a short exhaust duct. Soot properties were measured at the exit of the exhaust duct. Overfire soot physical properties were known for many of the fuels considered based on earlier work [2,4]. Soot volume fractions were measured by weighing soot collected on a filter while measuring the volume flow of gas over the collection period; this information combined with the known soot density yielded soot volume fractions at the test location.

Soot dimensionless extinction coefficients and other soot optical properties in the overfire region were found in the same way as before [2]. In particular, laser extinction and scattering properties were analyzed to indicate soot fractal dimensions, refractive index functions, refractive indices and dimensionless extinction coefficients based on RDG-PFA theory. Fuels considered included acetylene, ethylene, propylene, propane, benzene, toluene, cyclohexane, and n-heptane.

Results and Discussion. Similar to [2], present measurements confirmed that RDG-PFA theory was effective in the visible wavelength range (350-633 nm); notably, the evaluation included primary particle optical diameters as large as 0.46 which severely tests the approximations of this theory. Present scattering measurements in the visible established the fractal dimensions of the present soot at 1.8 with a standard deviation of 0.01 relatively independent of fuel type and properly independent of wavelength.

Present measurements of dimensionless extinction coefficients are plotted as a function of wavelength, in Fig. 1. Also shown on the figure are earlier measurements of this parameter for soot in the overfire region of crude-oil/air diffusion flames [7] and in the post-flame region of fuel-rich acetylene/air flames [8]. Present measurements exhibit little variation with wavelength and fuel type, except that results for acetylene soot are significantly lower than the other fuels. Thus, present results have been separated into two groups consisting of acetylene and the average for the rest of the fuels. Averaging the present results over all fuels and wavelengths yields a value of 8.6 with a standard deviation of 0.5. The results of Refs. 7 and 8 agree with this value within experimental uncertainties whereas in spite of extended efforts the somewhat smaller (by roughly 40%) values found by Wu et al. [2] could not be reproduced and it is recommended that they not be used in the future.

Present measurements of the refractive index functions E(m) and F(m), where m is the index of refraction of soot, are plotted in Fig. 2. Also plotted on the figure are earlier findings due to Dalzell and Sarofim [9], Batten [10], Lee and Tien [11], Chang and Charlampopoulos [12] and Vaglieco et al. [13]. Present results do not approach a resonance condition typical of graphite as uv is approached; instead, E(m) and F(m) decline continuously similar to recent observations for amorphous carbon and soot

[12,13]. Similar to the behavior of the dimensionless extinction coefficients, present measurements of E(m) and F(m) exhibit relatively little effect of fuel type except for acetylene soot which consistently yields smaller values of E(m) and F(m) than the rest. A number of earlier measurements [10-13] are not in good agreement with present measurements as the uv is approached because they involve questionable approximations when applying Drude-Lorence dispersion models or Kramers-Krönig causality relationship to close procedures to find soot refractive indices. These difficulties tend to disappear as the ir is approached where the various measurements are in better agreement, including the often criticized but widely used measurements of Dalzell and Sarofim [9].

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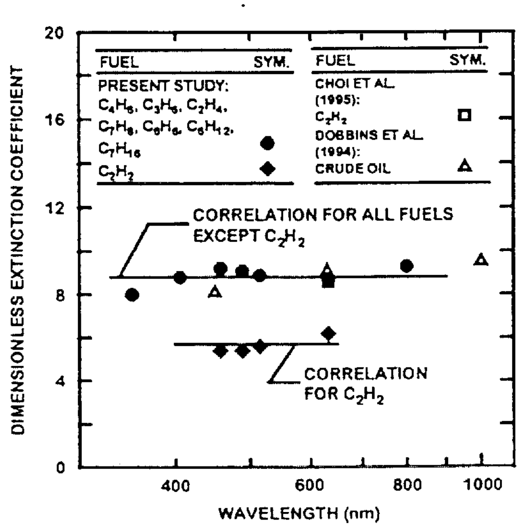

Fig. 1 Measured soot dimensionless extinction coefficients in the visible.

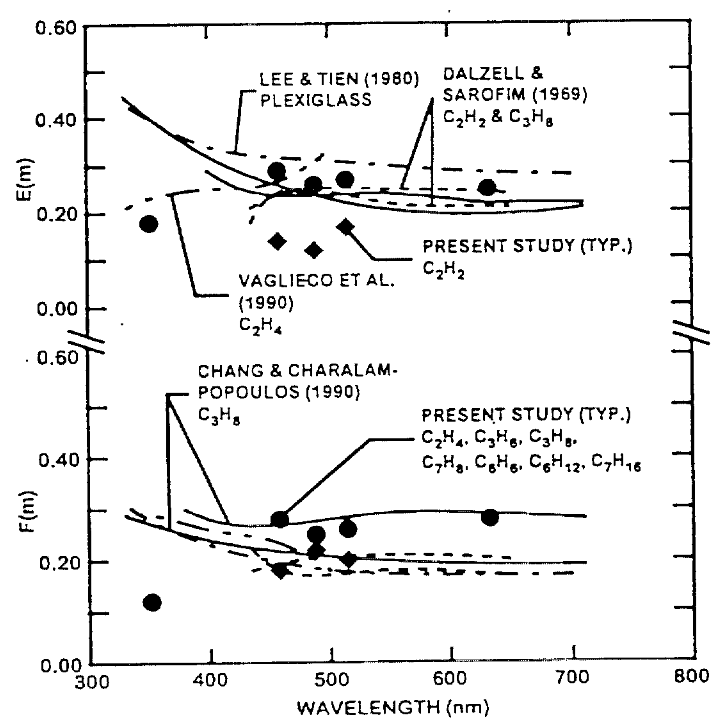

Fig. 2 Measured soot refractive index functions E(m) and F(m), in the visible.